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Comparative Exemination of the Strengthened and Non-Strengthened NIMONIC Specimens with Laser Shot Peening Method

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Abstract

Laser shot peening (LSP) of material strengthening is nowdays widely used method in various branches of industry. In this paper are presented comparative exeminations of specimen made of NIMONIC and strengthened specimen on which laser shot peening method was performed. Specimens were made as thin plates with holes. Macrostructural surface tests were performed around the specimens holes with different magnifications for both specimens as well as certain damages on the specimens. 3D images of specimens damages provide insights into the its dimensions. In addition, the roughness of non-strengthed and strengthed specimens was also performed. Hardness tests using the Rockwell C method of both specimens show a difference in the hardness of both samples and the main characteristics of the laser shot peening method. Also, the analysis on how the damage of samples could represent the location of initial cracks that could cause failure of the specimens or generally machine part is given as well.

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Keywords: Laser shot peening; Nimonic; Macrostructural surface tests.

1. Introduction

Nimonic, as a registered trademark, refers to a family of nickel-based high-temperature low creep superalloys. Nimonic alloys typically consist of more than 50% nickel and 20% chromium with additives such as titanium, aluminium etc. Nimonic alloys provide very good corrosion and oxidation resistance at very high temperatures and

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this characteristic allows it to be used in different industries. Nimonic alloys are used in aircraft parts and gas turbine components such as turbine blades and exhaust nozzles on jet engines, i.e. in parts with high pressure and temperature, but in automobile industry as well.

As mentioned before, this type of alloy has an application in automobile industry, i.e. in manufacturing of exhaust valves [1], aerospace industry, in turbine blades [2, 3], marine application [4], etc. Nimonic alloys are used for manufacturing of other gas turbine components such as rings and discs, bolts, nuclear boiler tube supports, die casting inserts and cores etc.

Nickel alloys are one of the toughest structural materials available nowadays and superalloys such as Nimonic are widely used in applications requiring strength at elevated temperature. Fracture of parts made of Nimonic type of alloys can be caused predominantly by creep or fatigue mechanism of failure. Kargarnejad et al. [3] described the case of failure assessment of gas turbine blade. In their paper a crack initiation/propagation in the coating was occur due to mixed fatigue/creep mechanism. One of the causes of crack initiation and propagation in the base metal could be due to grain boundary brittleness caused by formation of a grain boundary continuous film of carbides. Failure of an un-cooled turbine blade [5] shows that turbine blade had broken due to fatigue and excessive surface oxidation is the most probable cause of blade cracks. Macroscopically brittle intergranular creep fracture is presented by Hassan Farhangi et al. [6]. They have showed by fractographic examinations, an intergranular creep rupture by wedge-shaped cracking as the operating failure mechanism in the case of broken insert bolt of combustion chamber ring.

Lasers have been used for high precision material processing due to a specific nature of the laser light, such as high intensity and possibility of controlled surface modification. Treatment of nickel based superalloys' surfaces by laser irradiation can induce specific changes in the microstructure which result in improved mechanical properties of the material [7].

The principle of laser strengthening of material is using high intensity laser beam to generate high pressure shock waves on the surface of a workpiece [8]. The transient shock waves induce microstructure changes near the surface and alter the stress level, which improve the mechanical properties of material, such as hardness and fatigue strength [9].

The beneficial effects of laser strengthening of material include improvement of microstructure, surface quality, etc., which delays the initiating of fatigue cracking [10].

In this paper, the effects of LSP processing of nickel base superalloy Nimonic 263 is presented. The Nimonic 263 specimens are prepared as sheets, and the six holes are drilled in these sheets and after that strengthened by laser beams. Laser process parameters are set up at different pulse energy and pulse velocity levels. The microstructural and surface changes arisen by 1064 nm wavelength laser beam are discussed, as well as mechanical properties of laser treated material.

2. Experiment

In this experiment Nimonic 263 sheets, dimensions 130 x 12x 2 mm, prepared and drilled as it is shown in Figure 1, were laser treated using picosecond Nd:YAG laser. The scheme of the experimental setup is presented in Figure 2.

Fig. 1. Schematic of the specimens and prepared Nimonic 263 specimens

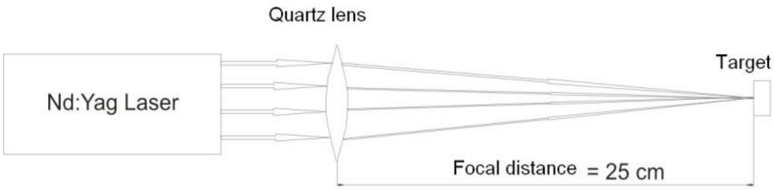


Fig. 2. Schematic of the experimental setup

Chemical composition of Nimonic 263 sheets are listed in Table 1. Nd:YAG laser specifications are listed in Table 2.

Table 1. Chemical composition in % of Nimonic 263

Element	C	Si	Mn	Al	Co	Cr	Cu	Fe	Mo	Ti	Ni
%	0.06	0.3	0.5	0.5	20	20	0.1	0.5	5.9	2.2	balance

Table 2. The characteristics of the EKSPLA picosecond laser

LASER	Nd:YAG
Wavelenght	1064 nm
Pulse duration	150 ps
Mode	about TEM00
Repetition rate	10 Hz

The resulting surface changes were determined by optical microscopy and compared with non–treated surface. Microhardness measurements were performed by the Rockwell C method on ZHU/zwickiLine universal hardness testing machine. Testing was performed by SRPS EN ISO 6508-1:2017 standard [11]. Also, surface morphology changes of the irradiated areas were analysed using Zygo NewView 7100 optical profiler, and characteristic surface parameters were calculated using MetroPro software.

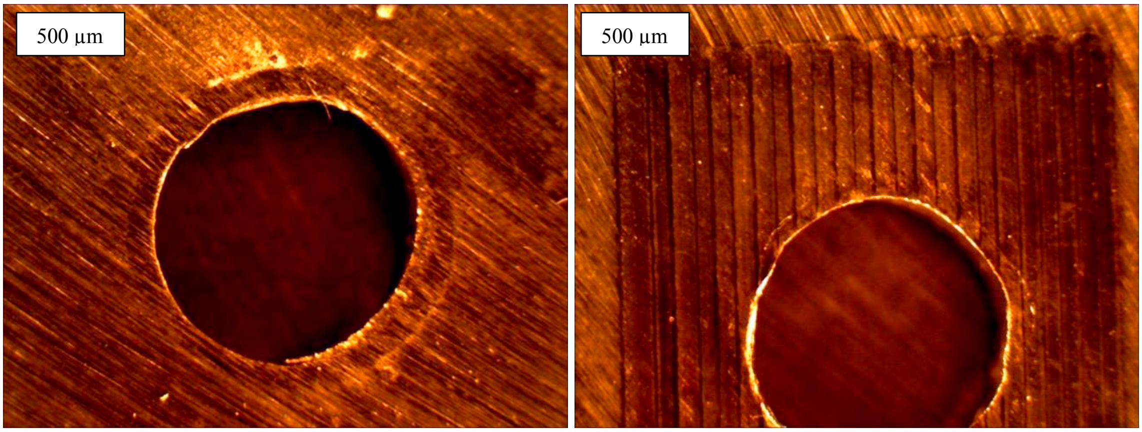
The samples are laser treated around the holes and the laser process parameters used in this experiment are listed in Table 3.

Table 3. Parameters of laser processing of Nimonic 263 sample

No. of hole	Laser energy [mJ]	treated area [mm x mm]	laser velocity [mm/min]
1	7	7 x 7	0.3
2	7	10 x 10	0.3
3	10	10 x 10	0.2
4	10	7 x 7	0.3
5	10	10 x 10	0.3
6	10	7 x 7	0.4

3. Results and discussion

In this paper, the areas around the holes are laser treated with the aim to strengthen the material around the drilled holes. Figure 3a. presents the appearance of the hole without the laser treatment taken by the light microscope, while Figure 3b. presents the area around the hole treated with laser parameters: E=/mJ and v=0.3mm/s, taken by light microscope. In Figure 3a. two zones are noticeable, one just around the hole, with unevenness, wideness up to 500 μm, and the second one around the first zone. After the laser treatment of material, the surface is more uniform (Figure 3b).



a. b.

Fig. 3. Microstructure around the holes a) without laser treatment; b) after the laser treatment, taken by light microscope

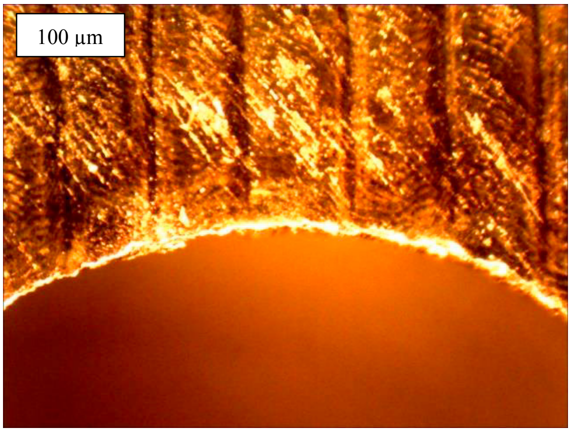


Fig. 4. Detail from the Figure 3b

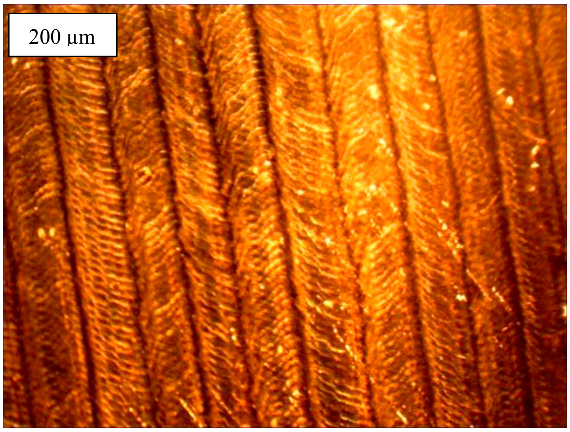


Fig. 5. Detail from the Figure 3b

Figure 4. presents the area near the hole, detail taken from Figure 3b. The zone 1 and uunevenness do not exist after the laser interaction. Figure 5. presents patern of laser treatment. Surface topology plays an important role in the parts used in aero mashine construction.

In Table 4. surface characteristics of the base material, and areas around the holes 1 – 6 are listed. In the first row the peak to valey values (PV) are given, in the second row rooth mean square (rms) and in third row the avarege roughness (Ra). analysing the values presented in Table 4. it can be noticed that laser treatment decreased the stated surface characteristics of the based material. Also, the laser energy and laser velocity affected the surface characteristics. With increasing the laser energy, the PV, rms and Ra also increase, and with increase the laser velocity, these values also increase. However, according to our results, the laser velocity has greater influence than laser energy. The surface characteristics are chenged from 10% to 45%. The laser treatment at least influenced the avarage roughness of the measured surface characteristics.

Figure 6. presents the 3D model, 2D map, surface profile and intensity map of the surface around the hole 1, treated with the laser parameters E=7mJ and v=0.3mm/min.

Table 4. Surface characteristics of base material, and areas around the holes 1 - 6

	BM	1	2	3	4	5	6
PV [µm]	3.818	2.134	2.130	2.192	2.692	2.666	3.143
rms [µm]	0.648	0.445	0.344	0.389	0.396	0.447	0.726
Ra [µm]	0.483	0.359	0.290	0.362	0.474	0.359	0.626

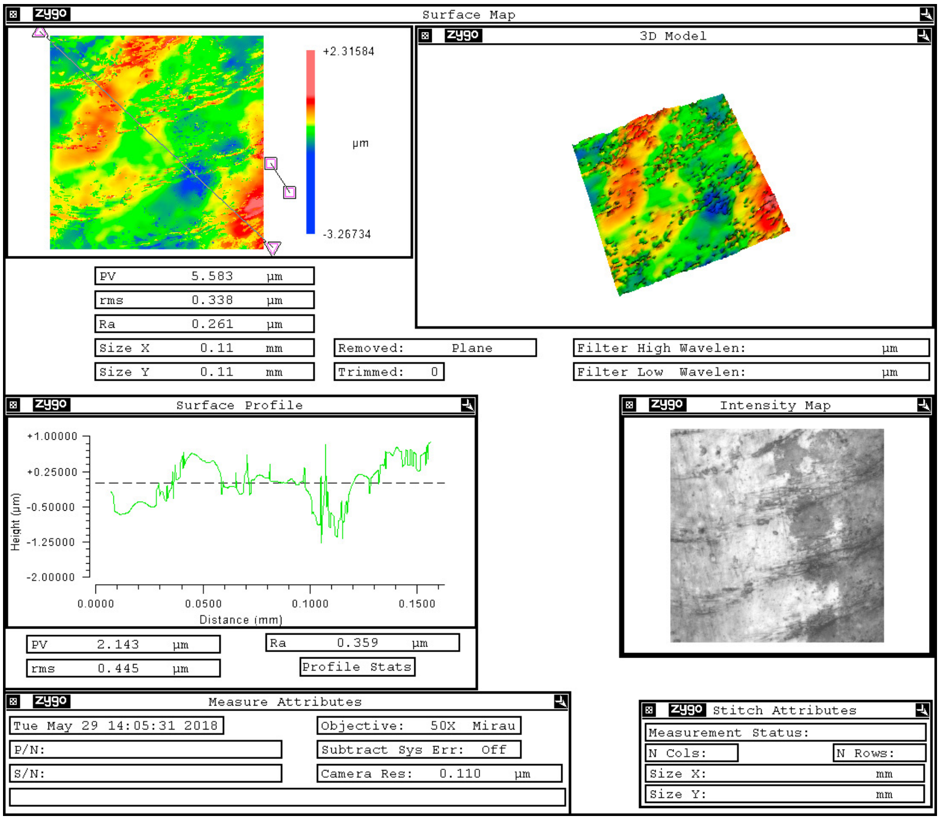


Fig. 6. 3D model, 2D map, surface profile and intensity map of area around the hole 1

Figure 7. shows results for hardness tests of both specimens using the Rockwell C method, and results show a difference in the hardness of samples and the main characteristics of the laser shot peening method. Results for hardnes measurment on specimens without laser treatment are 24 HRC and on specimens after the laser treatment 26 HRC.

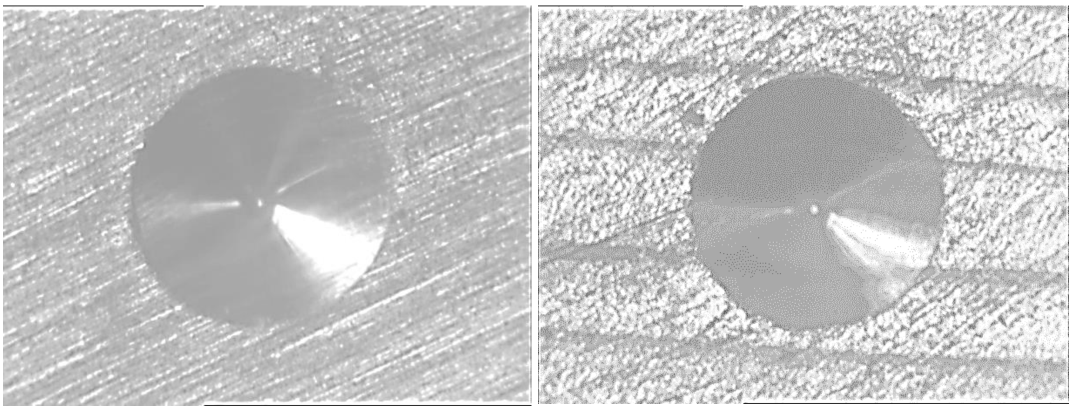


Fig. 7. Rockwell C method results for specimens a) without laser treatment; b) after the laser treatment

4. Results and discussion

In this paper, the surface microstructural changes of superalloy Nimonic 263 induced by picosecond laser mechanical treatment were discussed. The following conclusion can be drawn from this study.

- The laser action produces more uniform structure around the holes.

- The laser action decreases the surface characteristics of material around the holes. However, by increasing the laser energy and laser velocity, the surface characteristics increased again;
- The laser beam processing improves the microhardness of material around the holes. However, there is no significant difference of laser impact on microhardness of material between the various laser parameters applied in this experiment.

By analyzing these results it can be concluded that in order to obtain beneficial mechanical characteristics of the observed material laser treatment by picosecond laser can be used as a promising technique for superalloy's surface processing.

Acknowledgements

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References

[1] Myagkov, L.L., Mahkamov, K., Chainov, N.D., Makhkamova, I., 2014. Advanced and conventional internal combustion engine materials, Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance, Pages 370-392.
[2] Lucacci, G., 2017. Steels and alloys for turbine blades in ultra-supercritical power plants, Materials for Ultra-Supercritical and Advanced Ultra-Supercritical Power Plants, Pages 175-196.
[3] Kargarnejad. S., Djavanroodi, F., 2012. Failure assessment of Nimonic 80A gas turbine blade, Engineering Failure Analysis, Volume 26, Pages 211-219.
[4] Bagui, S., Ray, A. K., Sahu, J.K., Parida, N., Swaminathan, J., Tamilselvi, M., Mannan, S.L., 2013. Influence of saline environment on creep rupture life of Nimonic-263 for marine turbine application, Materials Science and Engineering: A, Volume 566, Pages 54-60.
[5] Mishra, R. K., Thomas, J., Srinivasan, K., Nandi, V., Raghavendra Bhattc, R., 2017. Failure analysis of an un-cooled turbine blade in an aero gas turbine engine, Engineering Failure Analysis, Volume 79, Pages 836-844.
[6] Farhangi, H., Samimi, P., 2007. Fractographic and Microstructural Investigation of the Failure ff High Temperature Nimonic 80A Insert Bolts, Prooceedings of 8th International Fracture Conference, Turkey.
[7] Petronic, S., Milovanovic, D., Milosavljevic, A., Momcilovic, M., Petrusko, D. 2012. Influence of picosecond laser irradiation on nickel-based superalloy surface microstructure. Phys Scripta, T 149, 014079- 014083, doi:10.1088/0031-8949/2012/T149/014079..
[8] Yilbas, B.S., Shuja, S.Z., Arif, A., Gondal, M.A., 2003. Laser-shock processing of steel. J Mater. Proc. Technol., doi:10.1016/S0924-0136(02)00813-0.
[9] Peyre, P., Fabbro, R., Berthe, L., Dubouchet, C., 1996. Laser shock processing of materials, physical processes involved and examples of application. J. Laser Appl., 8, 3, 135–141, http://dx.doi.org/10.2351/1.4745414.
[10] Ding, K., Ye, L., 2006. Laser shock peening, Performance and process simulation; Woodhead publishing limited: Cambridge, England, pages 50-53.
[11] SRPS EN ISO 6508-1:2017: Metallic materials - Rockwell hardness test - Part 1: Test method.